SONNTAG

Investigation of the magneto as an electric machine

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INVESTIGATION OF THE MAGNETO AS AN ELECTRIC MACHINE

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ARTHUR HENRY SONNTAG

ENTITLED INVESTIGATION OF THE MAGNETO AS AN ELECTRIC MACHINE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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INTRODUCTION

In the last few years the developement of the motor driven vehicle has brought along with it a class of electric machine whose general principles are well known but whose individual characteristics have been little investigated. This machine is the so called high tension magneto, which in reality may not be a high tension magneto as will be shown later, and which is almost universilly used for automobile gas engine ignition today. It takes the place of the battery, and also of the spark coils to a certain extent. Thus we may expect to find in the magneto a transforming winding to change the low potential energy to a higher potential as is necessary to arc over the gap of the spark plug in the engine cylinder, as well as a source of electrical energy.

These magnetos may be divided into three general types, namely: the low tension, a combination type, and the strictly high tension. All of these generate a low potential alternating current in an armature which revolves between the poles of compound permanent magnets, and the difference in classification depends upon where the high potential is generated. In the low tension type the low potential is generated in the armature and is then carried to an independent transformer winding where it is raised to a high potential. In the combination type the transformer winding is fixed permanently to the magneto frame while in the high tension type, the high potential is produced in the armature of the magneto itself. The principle upon which the production of the spark depends is the same for all three and is the same as can be applied to the ordinary "jump spark" coil.

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[illegible]

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Hence any theory which may be given for the induction coil will apply equally well to the high tension magneto.

It is the purpose of this paper to give the theory of the magneto and also to give the results of tests upon two representative magnetos, one being of the low tension type and the other of the high tension type. Since the true efficiency of the magneto is in the heat of spark produced in the spark plug of the engine, some tests in this direction have also been included.

THEORY.

The essentials for the production of a high potential for the ignition of the gas engine is a source of electromotive force, a coil of coarse wire, and a circuit interrupting device. Wound upon the coil of coarse wire is a coil of fine wire having a very great number of turns. A capacity across the interrupter will improve the secondary voltage as will be shown later. If a battery and coil are used, the current at the instant of break is the first essential to be determined. Let E be the e.m.f. of the battery, R the resistance of the primary winding, L the inductance of the primary, and i the instantaneous value of current. Then the battery e.m.f. will be counter acted by the drop due to resistance and the e.m.f. of self induction: or

$$E = Ri + L\frac{di}{dt}$$

Separating variables we have $\frac{dt}{L} = \frac{di}{E-Ri}$

Integrating we have $\frac{t}{L} = -\frac{1}{R}\log(E-Ri) + C$

and when t = 0, i = 0 so that $C = \frac{1}{R}\log E$

Thus we have $\frac{E-Ri}{E} = \varepsilon^{-\frac{Rt}{L}}$,

and $i = \frac{E}{R}\left(1-\varepsilon^{-\frac{Rt}{L}}\right)$

In the magneto however, the instantaneous value of current depends upon the short circuit current wave of the magneto. This in turn depends upon the flux wave, the speed of rotation of the armature, the resistance and self induction of the armature, and the armature reactions. Owing to the great number of variables coming in, the curve can best be obtained by means of an oscillograph record, from which the instantaneous values can readily be taken.

It is interesting to note upon what the generated voltage and current in a circuit depend when a current is stopped. Assuming a circuit of inductance L and resistance r, and letting i_0 be the instantaneous value of current flowing in the circuit due to the impressed e.m.f. E, remove the e.m.f. E and close the circuit through a resistance r_1. For a short circuit r_1 equals zero and for an open circuit it will equal infinity. Let i be the current at the time t after the removal of the e.m.f. E, and di be the change of current during the time interval dt. Then the e.m.f. generated thereby will be $e_1 = -L\frac{di}{dt}$

The current will be $i = \frac{e_1}{r+r_1} = \frac{-L}{r+r_1}\frac{di}{dt}$

Integrating between the limits 0 and t, we find

$$i = \frac{E}{r}\varepsilon^{-\frac{(r+r_1)t}{L}} \quad \text{and} \quad e_1 = i(r+r_1) = E\frac{r+r_1}{r}\varepsilon^{-\frac{(r+r_1)t}{L}}$$

Substituting $i_0 = \frac{E}{r}$

$$i = i_0\,\varepsilon^{-\frac{(r+r_1)t}{L}}$$

$$e_1 = i_0(r+r_1)\,\varepsilon^{-\frac{(r+r_1)t}{L}}$$

Thus we find that if the circuit is opened instantaneously, $r_1 = \infty$, and $t = 0$, and the e.m.f. rises infinitely.

The total energy of the generated e.m.f. and current is $W = \int_0^\infty i e_1\,dt$ which reduces to $W = 1/2\, i_0^2\, L$

However under actual conditions the current cannot be interrupted instantly and thus a value of r_1 will enter which will contain many variables and the result will be that e_1 will rise to some definite value depending upon the conditions of break. The energy expended in stopping the current will be $1/2\, i_0^2\, L$ since this is independent of the resistamces r and r_1.

In order to show more clearly the action under different conditions, the following oscillographs of an induction coil are given.

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[illegible]

[illegible]

[illegible]

[illegible]

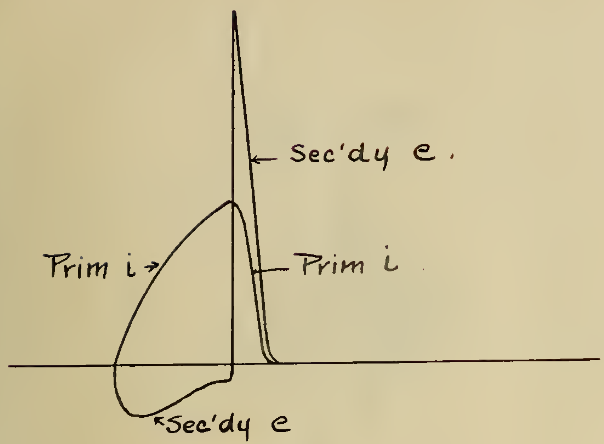


Figure 1.

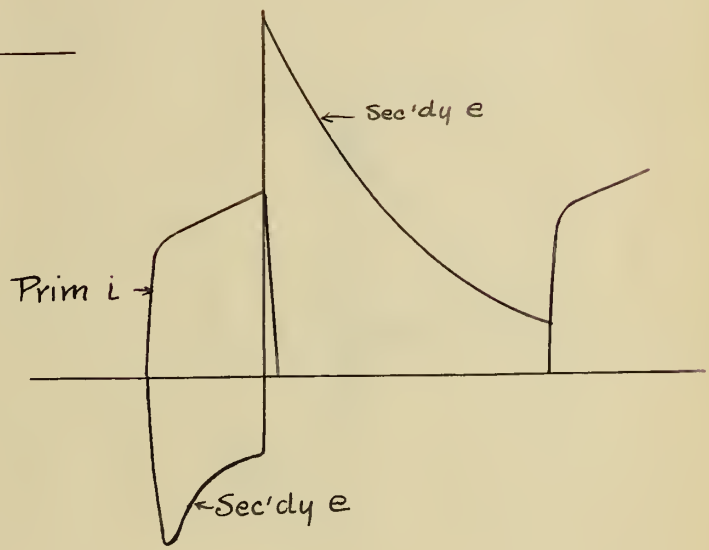


Figure 2.

Figure 1 shows the primary current curve and the secondary e.m.f. of a coil without condenser and the secondary open. Figure 2 shows the same curves for the secondary loaded with a non-inductive resistance. Here we notice that the primary current rises very rapidly due to the current induced in the secondary. At the break a high e.m.f. is produced in the secondary and a large current begins to flow through it. This current is in the same direction as the primary current and thus the primary current can drop rapidly without the flux changing.

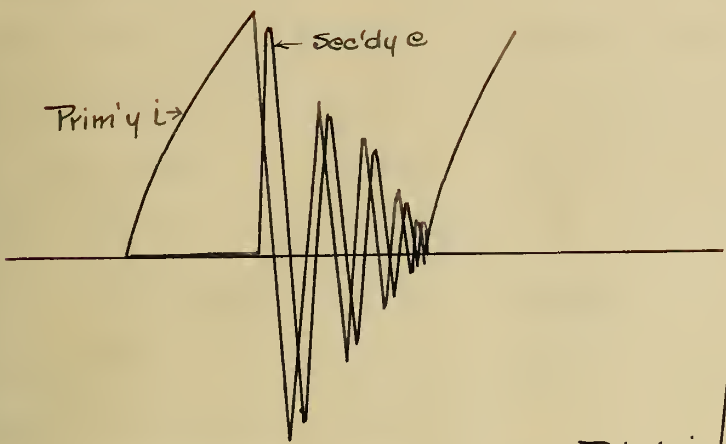


Figure 3.

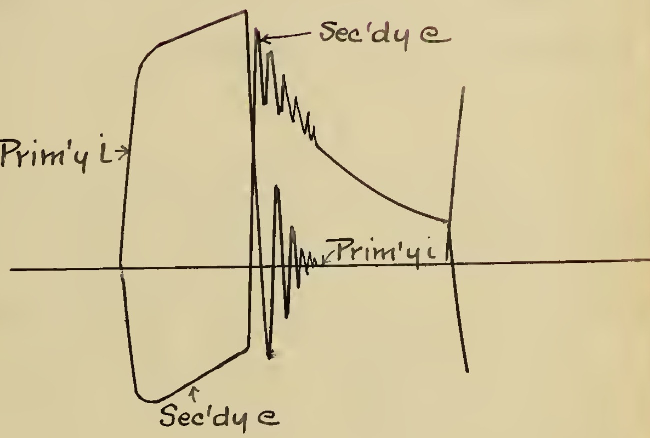


Figure 4.

Figure 3 shows the action of the condenser with the secondary open and Figure 4 shows the action with the secondary loaded. Here we will notice that with the secondary open the oscillations are of considerable amplitude, while with the secondary loaded the oscillations are damped out due to a considerable current flowing through the resistance of the coil. The condenser as used above is shunted around the contact breaker in the primary circuit.

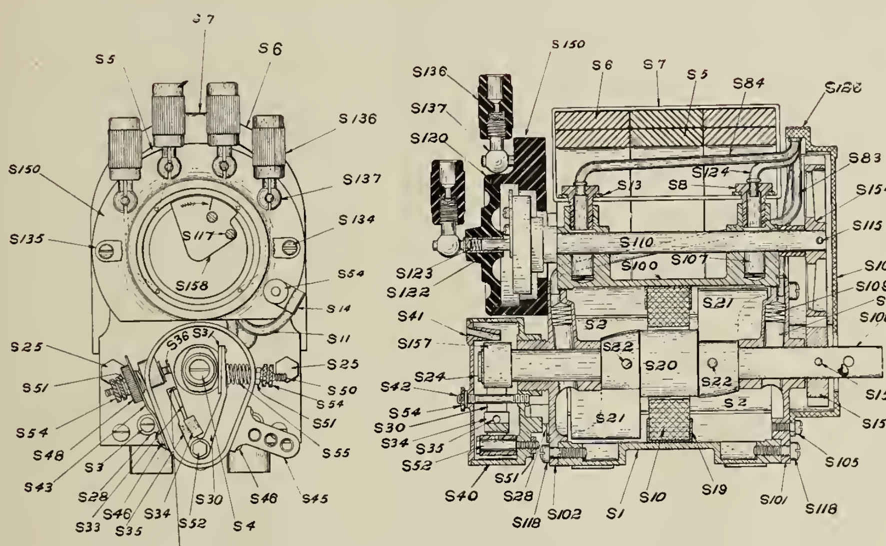
The rise in voltage in a circuit of inductance L and capacity C is $i\sqrt{\frac{L}{C}}$, and thus the maximum secondary voltage is $-\frac{N_s}{N_p}\sqrt{\frac{L}{C}}\,i$ where i is the current at the instant of break, L the inductance of the primary coil in henries, C the capacity of the condenser in

farads, N_s the turns in the secondary, and N_p the turns in the primary. Thus the essentials for a high secondary e.m.f. are: a large ratio of secondary to primary turns, a large current at break, fairly high inductance L, and a small capacity across the interrupter. The capacity, however, should not be made too small since this would permit of more sparking at the contacts which would reduce the voltage more than what was gained by reduction of the capacity. Thus generally very small capacities are used, the value depending upon the nature of the break.

The maximum output per spark is then $1/2\ L\ i^2$, but due to sparking at the contacts and loss in the iron core, the actual output will be about twenty per cent less and is expressed in joules. The maximum e.m.f. in the secondary at break is $-\frac{N_s}{N_p}\sqrt{\frac{L}{C}}\,i$ when the secondary is open and the condenser is of sufficient size to prevent sparking at the contacts. However, if there is current flowing in the secondary, the e.m.f. will be somewhat less.

DESCRIPTION.

In the description and tests of these magnetos, the low tension magneto will be designated by "A", and the high tension magneto will be designated by "B".



End View of Magneto **Longitudinal Section of Magneto**

CONSTRUCTION

S40—Timer Housing for left hand Magneto
S40½—Timer Housing for right hand Magneto
S41—Timer Housing Lid
S25—Hex. Cap Screw
S43—Insulated Screw Clip
S42—Timer Lid Stud
S30—Cam Lever, with hardened steel plate No. S31
S52—Timer Lever Shaft
S55—Lever Coil Spring
S33—Contact Spring, with platinum point No. S36
S34—Cam Lever Spring Block
S35—Cam Lever Spring Block Screw
S48—Contact Screw Insulation, with contact screw No. S47 and platinum point No. S36
S50—Ground Screw
S51—Ground Screw Nut
S54—Binding Nut
S157—Cam for 4 or 6 cylinders (No. S184 for 1, 2 or 3 cylinders)

S 23—Cam Pin
S 24—Cam Plate
S 4—Inductor Shaft Screw
S 45—Timer Shifting Lever
S 46—Shifting Lever Screw
S 49—Shifting Lever Lock Washers
S154—Large Gear for 4 cylinders (No. S174 for 3 or 6 cylinders)
S155—Small Gear for 4 cylinders (No. S175 for 3 or 6 cylinders)
S115—Large Gear Pin
S156—Small Gear Pin
S150—Distributer Case for 4 cylinders (No. S170 for 6 cylinders)
S116—Spacing Collar
S137—Secondary Terminal
S136—Secondary Terminal Insulation
S134—Distributer Lid Spring Screws
S135—Distributer Lid Springs
S133—Distributer Bolts

S120—Distributer Lid with brush-holder No. S121
S122—Carbon Brush
S123—Carbon Brush Spring
S158—Segment
S110—Distributer Shaft with Disc
S101—Drive End Bearing for 3, 4 or 6 cylinders. (No. S185 for 1 or 2 cylinders)
S102—Timer End Bearing for 3, 4 or 6 cylinders. (No. S186 for 1 or 2 cylinders)
S126—Oiler Name Plate
S 83—Long Oiler Tube
S107—Oil Wick
S109—Wick Spring
S118—End Bearing Screws
S104—Gear Case
S105—Gear Case Screws
S 28—Timer Stop
S 3—Timer Stop Screws
S 5—Inside Magnet
S 6—Outside Magnet
S 7—Magnet Clamp Strap
S 8—Magnet Clamp Strap Screws
S 13—Lock Washer for S8

Magneto "A".

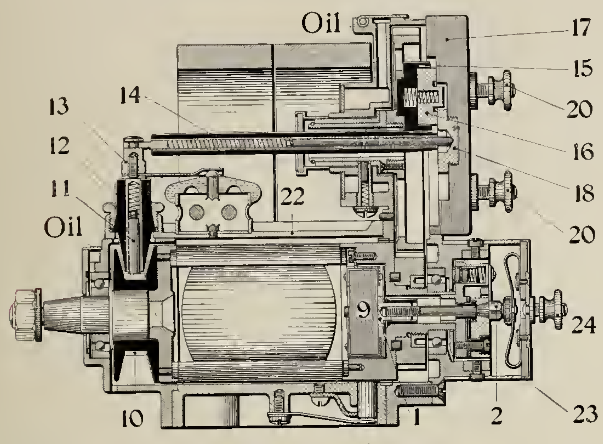
The magneto "A" has a single winding of coarse wire which is stationary, shown as S10, and through which the shaft with two steel inductors, one on each side, revolves. These inductors form the armature iron and are set diametrically opposite. Thus during one revolution the flux first passes through the coil in one direction and then in the other direction, thereby producing two impulses of electromotive force. The coil is then connected through a mechanical interrupter to the primary of the transformer coil which is independent of the machine. The spark may be timed by shifting the cams so as to break the circuit earlier or later as desired.

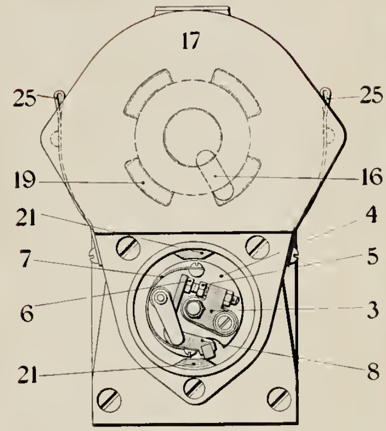
The high voltage from the secondary of the transformer is carried back to the magneto where it goes through the distributer which switches it to the proper engine cylinder at the proper time. Thus with a four cylinder four cycle engine, two cylinders have explosions during one revolution, and the magneto will have to be run at engine speed to give the two sparks required during the revolution.

The magneto "B" has a shuttle armature revolving between the poles of permanent magnets and has the primary winding and the secondary winding wound together upon the armature. Thus the primary winding serves as a generating winding of the magneto and also as the primary winding of the transformer. The secondary being wound upon the same core as the generating winding is a very efficient combination, the leakage and the total core loss being less than it would be for a separate transforming coil. The primary winding is of heavy wire while the secondary winding is of a large number of turns of fine wire. The windings are arranged as shown in the diagram with a condenser connected across the circuit breaking device,

1. Brass plate for connecting the end of primary winding.
2. Fastening screw for contact breaker.
3. Contact piece in contact breaker.
4. Contact breaker disc.
5. Long platinum screw.
6. Short platinum screw.
7. Contact breaker spring.
8. Bell crank lever.
9. Condenser.
10. Slip ring.

Longitudinal Section of the Magneto.

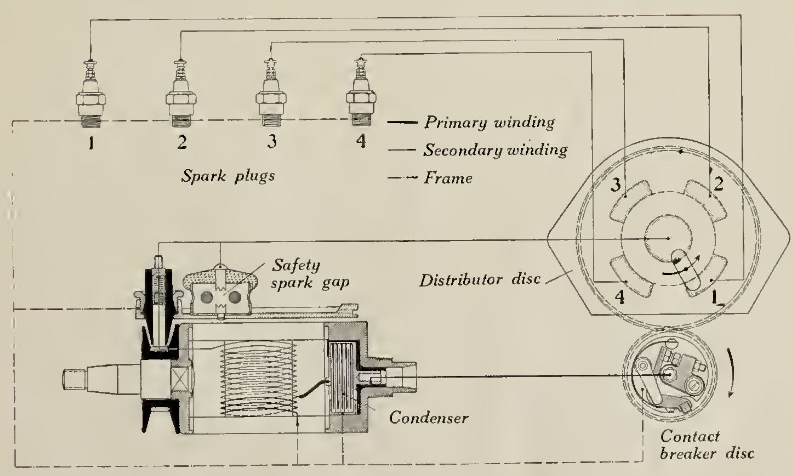




11. Carbon for conducting the current.
12. Carbon holder.
13. Fastening nut on carbon holder.
14. Spring contact for conducting the current.
15. Rotating insulation piece.
16. Distributor carbon brush.
17. Distribution disc.
18. Centre distributor contact.
19. Metal segments.
20. Connection terminal.
21. Steel segments.
22. Dust cover.
23. Protecting cover.
24. Nut for short circuiting terminal.
25. Spring for holding distributor disc 17.

Magneto "B".

Diagram of Wiring.



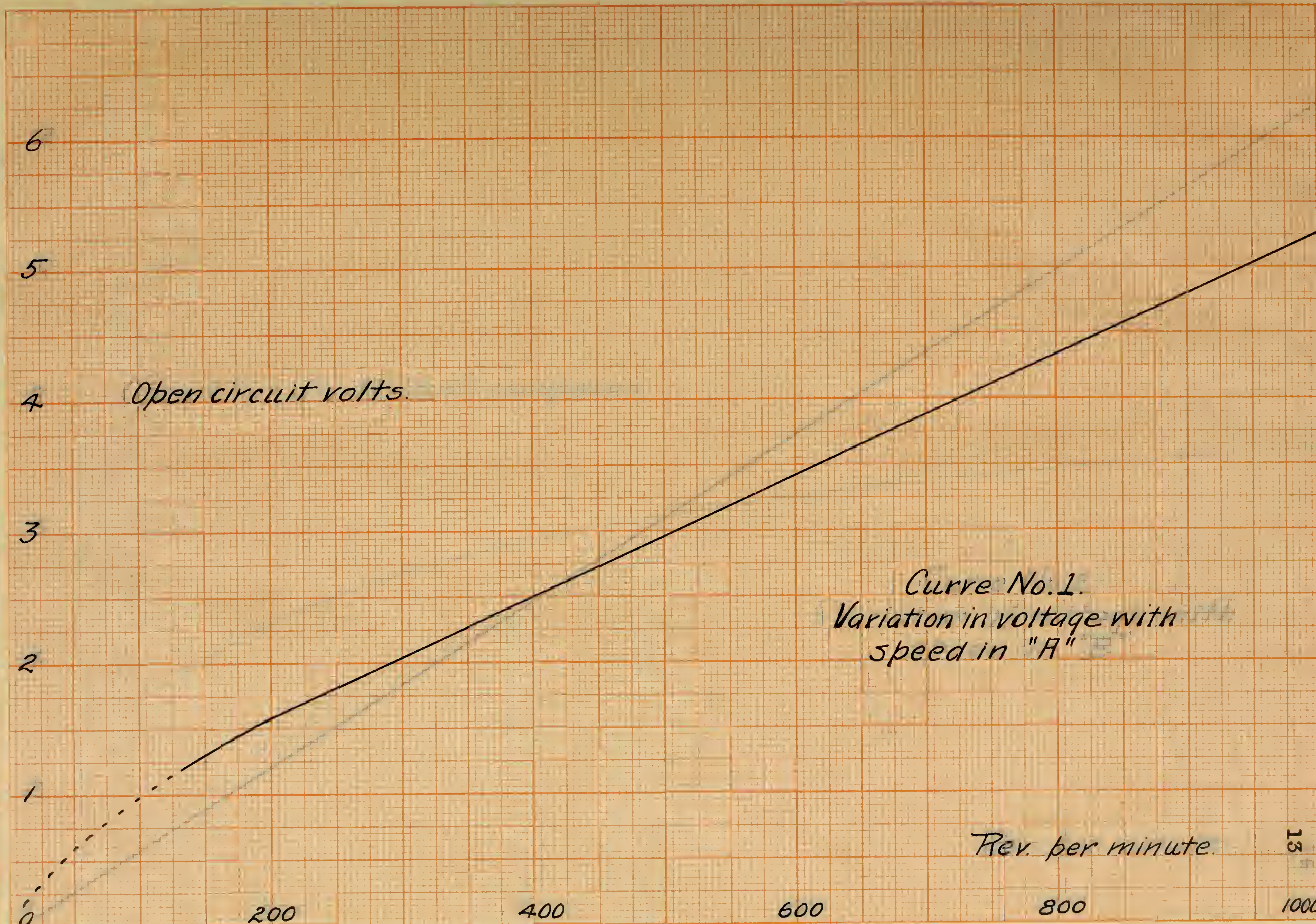
this condenser being mounted directly in the armature body. The common terminal of the primary and secondary winding is grounded upon the machine, while the other primary terminal connects to the contact breaker, which short circuits the primary winding and then opens the circuit when a spark is to be produced. The other terminal of the secondary winding connects to the rotating brush in the distributor. With the shuttle type of armature there are two impulses of electromotive force generated per revolution, so that the magneto will have to be run at engine speed in order to give two sparks during one revolution of the engine. The distributer operates in the same manner as described for magneto "A".

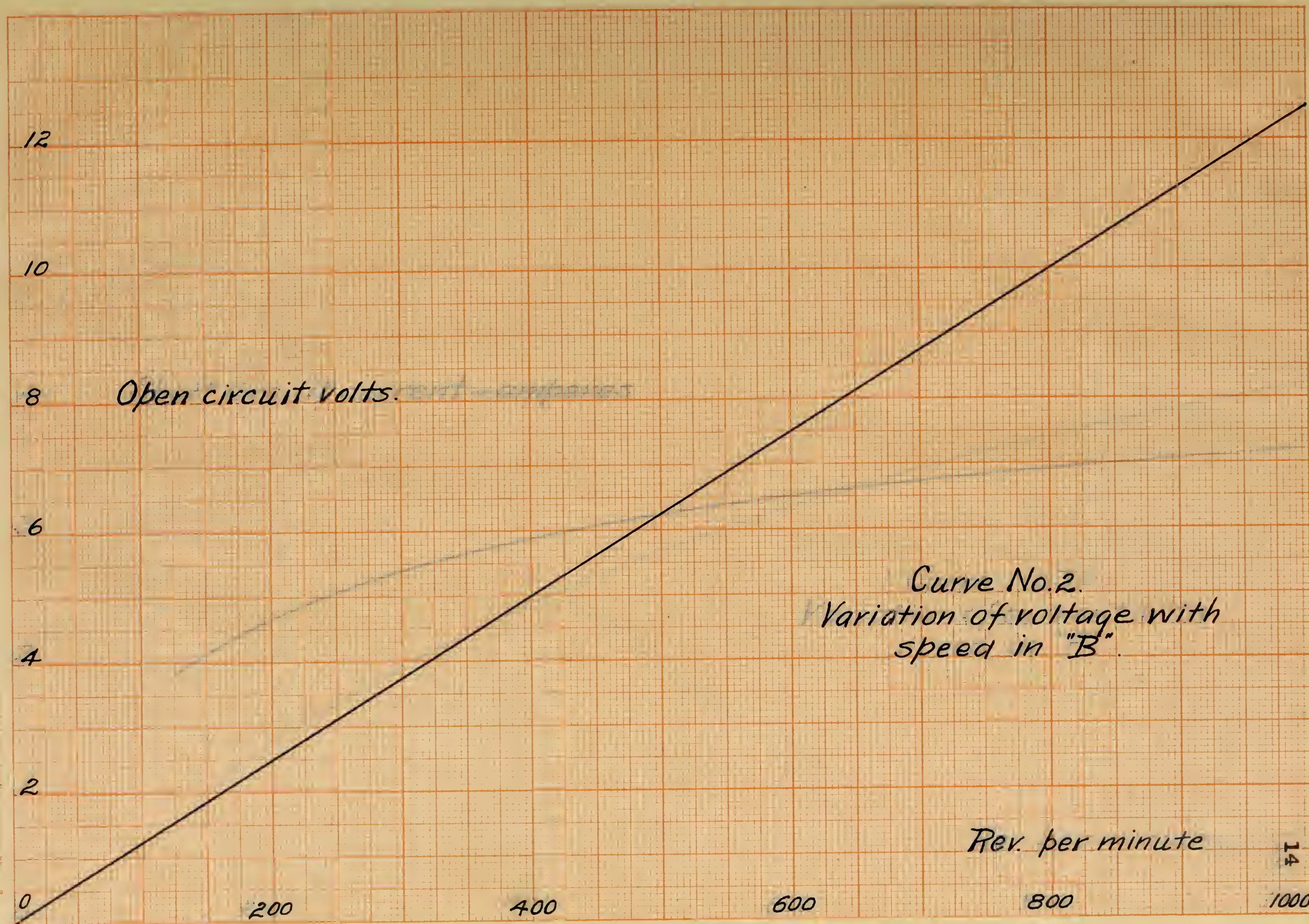
TESTS.

The automobile engine as used varies in speed from 500 revolutions per minute to 1500 revolutions per minute, the range varying considerably in different engines. Since the magneto operates at engine speed, its speed will vary through the same range, and an average operating speed may be taken as about 900 revolutions per minute. Thus for the following tests, a speed of 900 revolutions has been used as a representative condition of affairs.

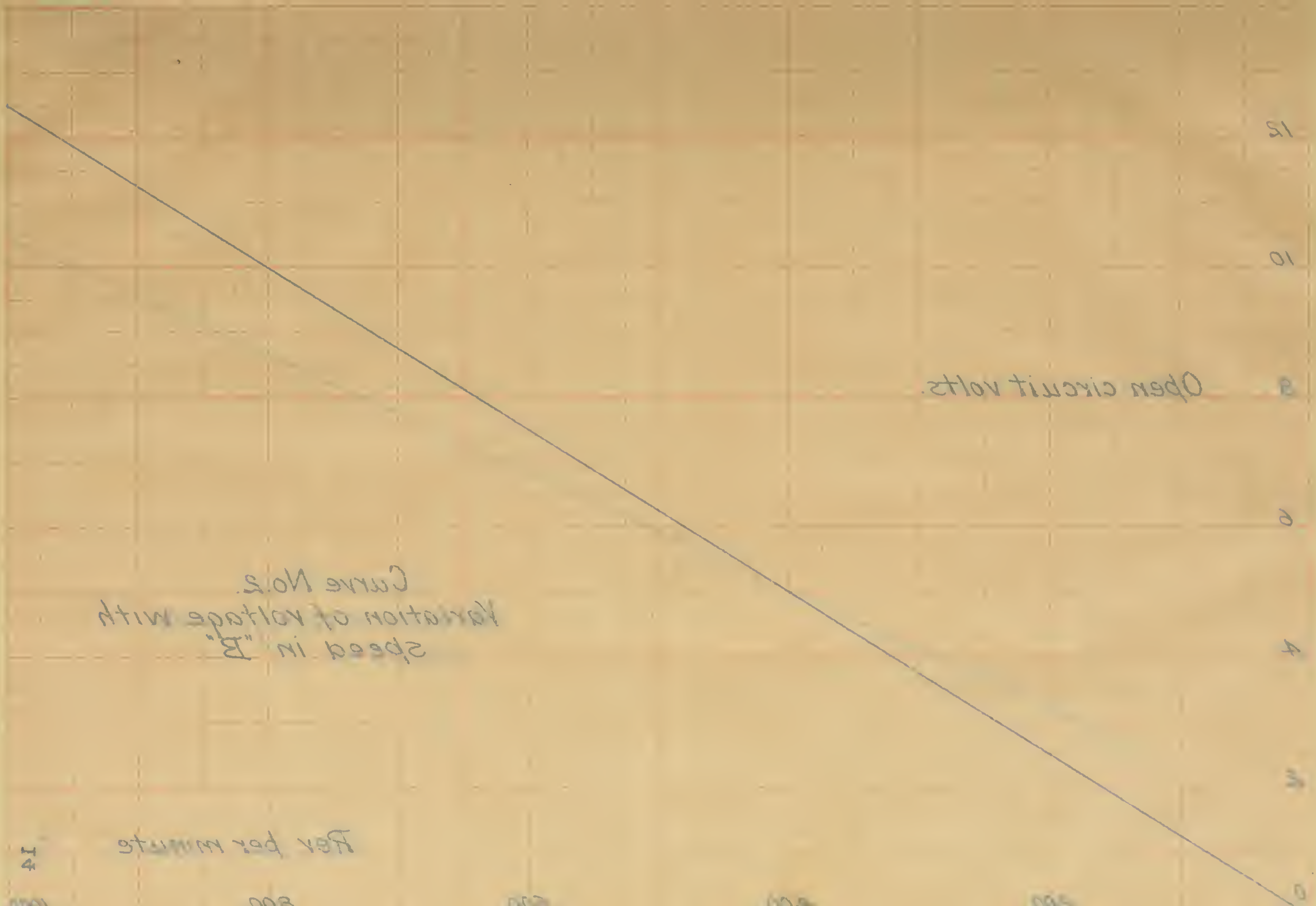
The first test is to show the variation of the open circuit voltage of the magneto as a generator with speed ranging from about 150 revolutions per minute to 1000 revolutions per minute which is given by curves #1 and #2. These curves will be discussed later. Since the short circuit current is very important in the production of the high secondary e.m.f., the variation of the same with speed is also given and is shown by curves #3 and #4. The generator characteristics of the two machines are given by curves #5 and #6, being taken at 900 revolutions per minute. From the last two curves the power curve for each machine has been plotted and is shown by curves #7 and #8.

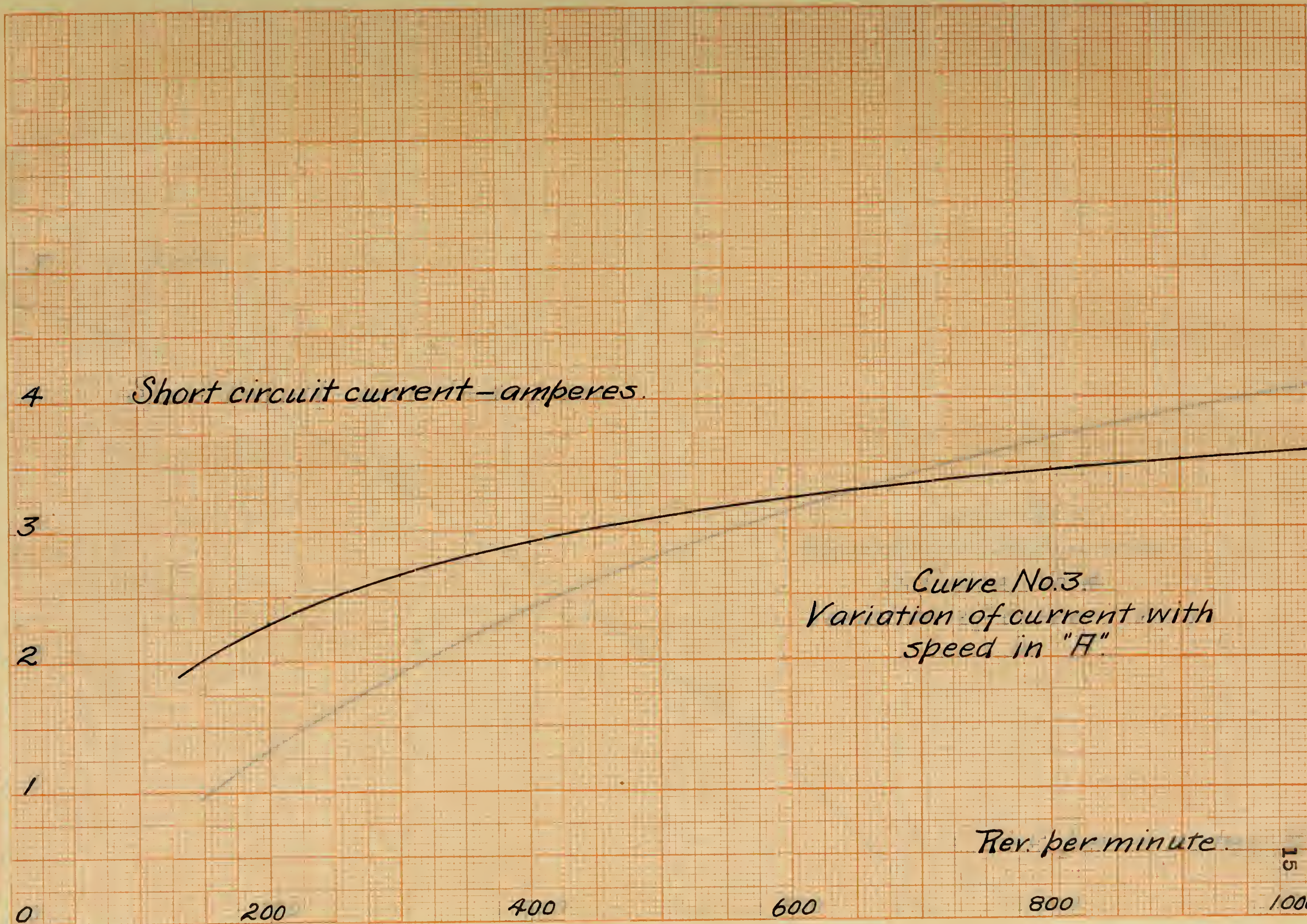
The voltage curve of the two machines is a straight line, the voltage of machine "B" being about twice that of machine "A" at the speed of 900 revolutions per minute. The short circuit current of machine "B" at the above speed is about 14% higher than that of machine "A", while the current curve for "A" is more flat at the higher speeds than the current curve of "B". The voltage drops off very rapidly with the increase of load for both machines, indicating a high armature resistance. The maximum power developed by

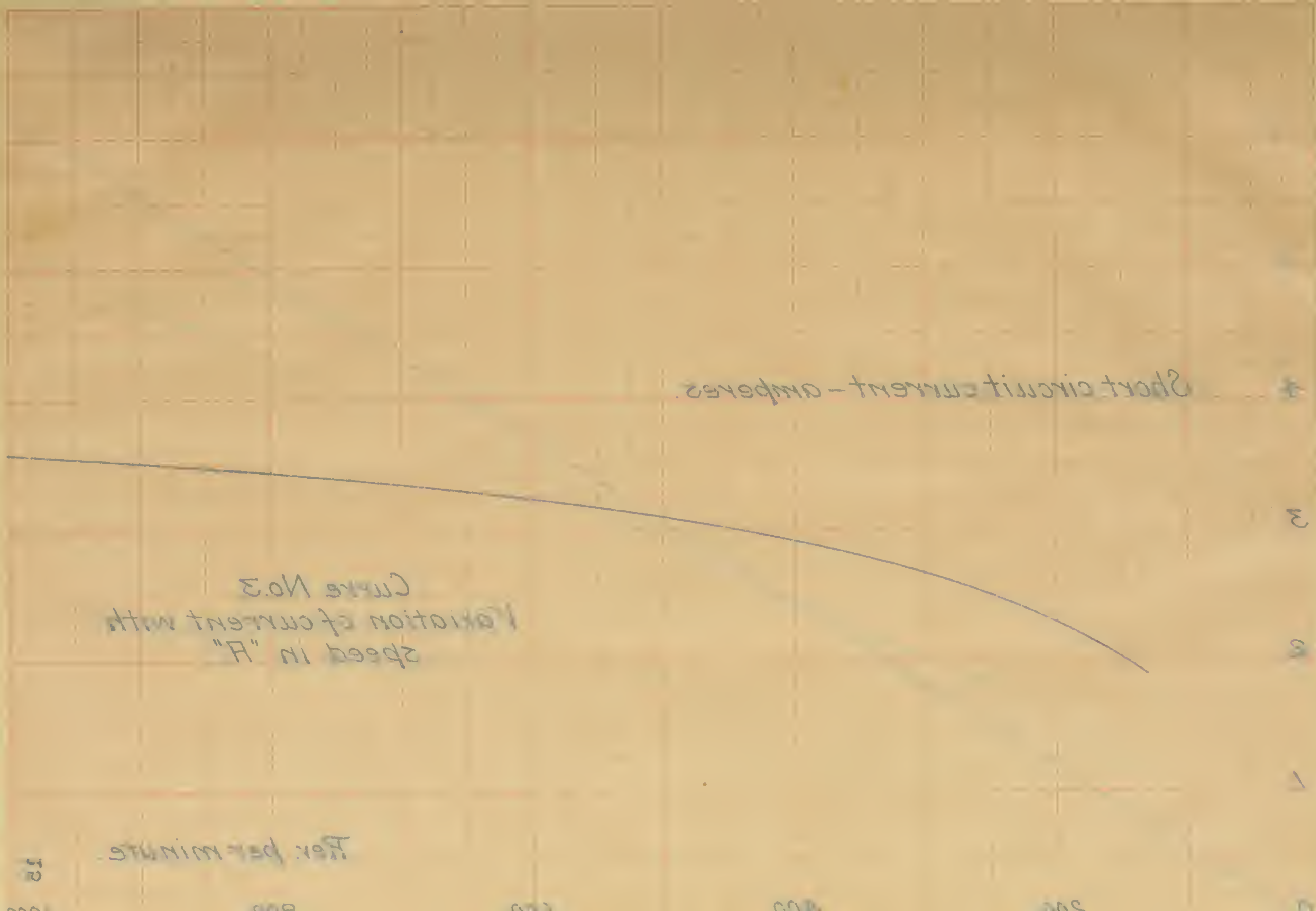

Open circuit volts.
Curve No. 1.
Variation in voltage with
speed in "A"
Rev. per minute.
0
1
2
3
4
5
6
200
400
600
800
1000

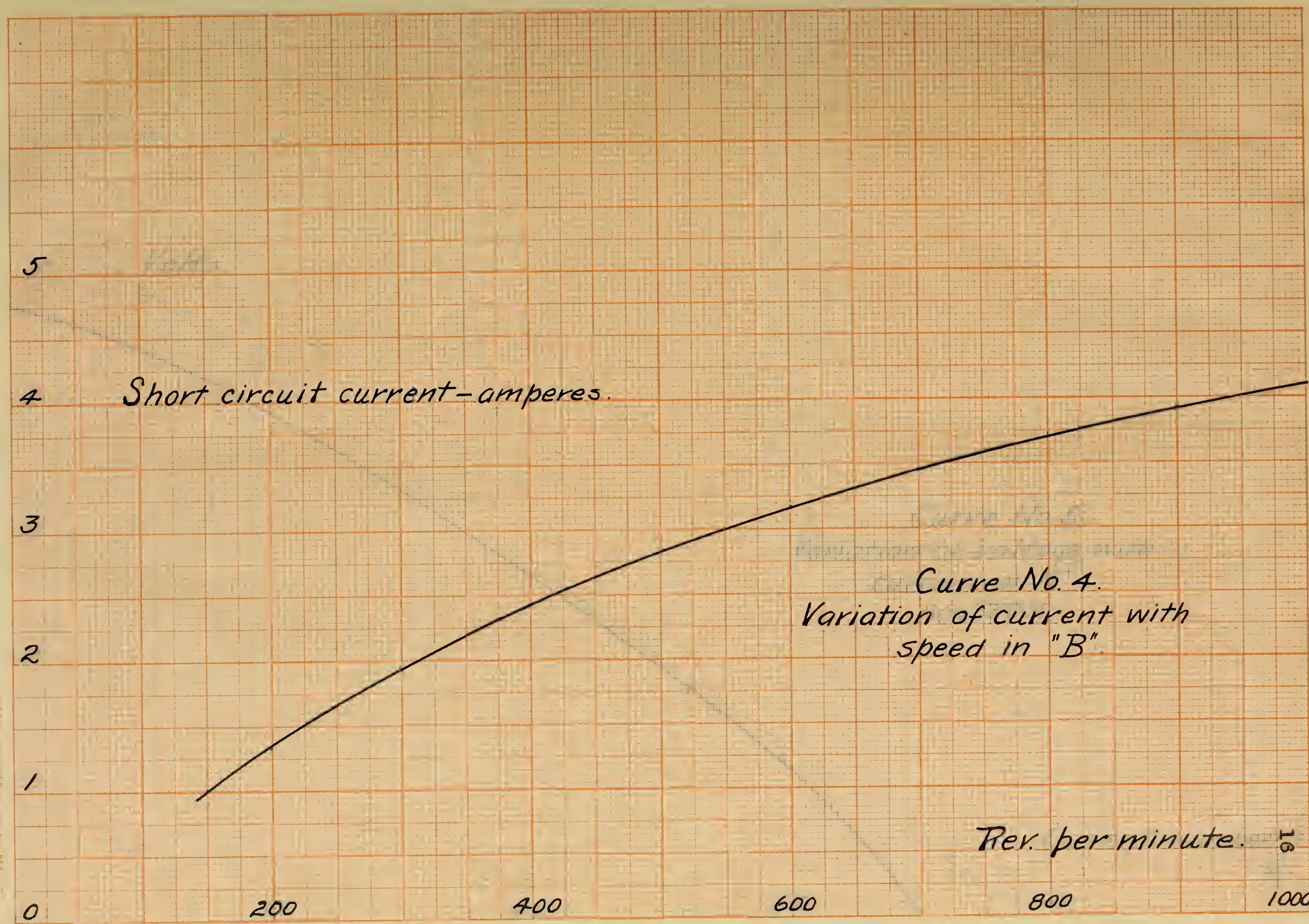


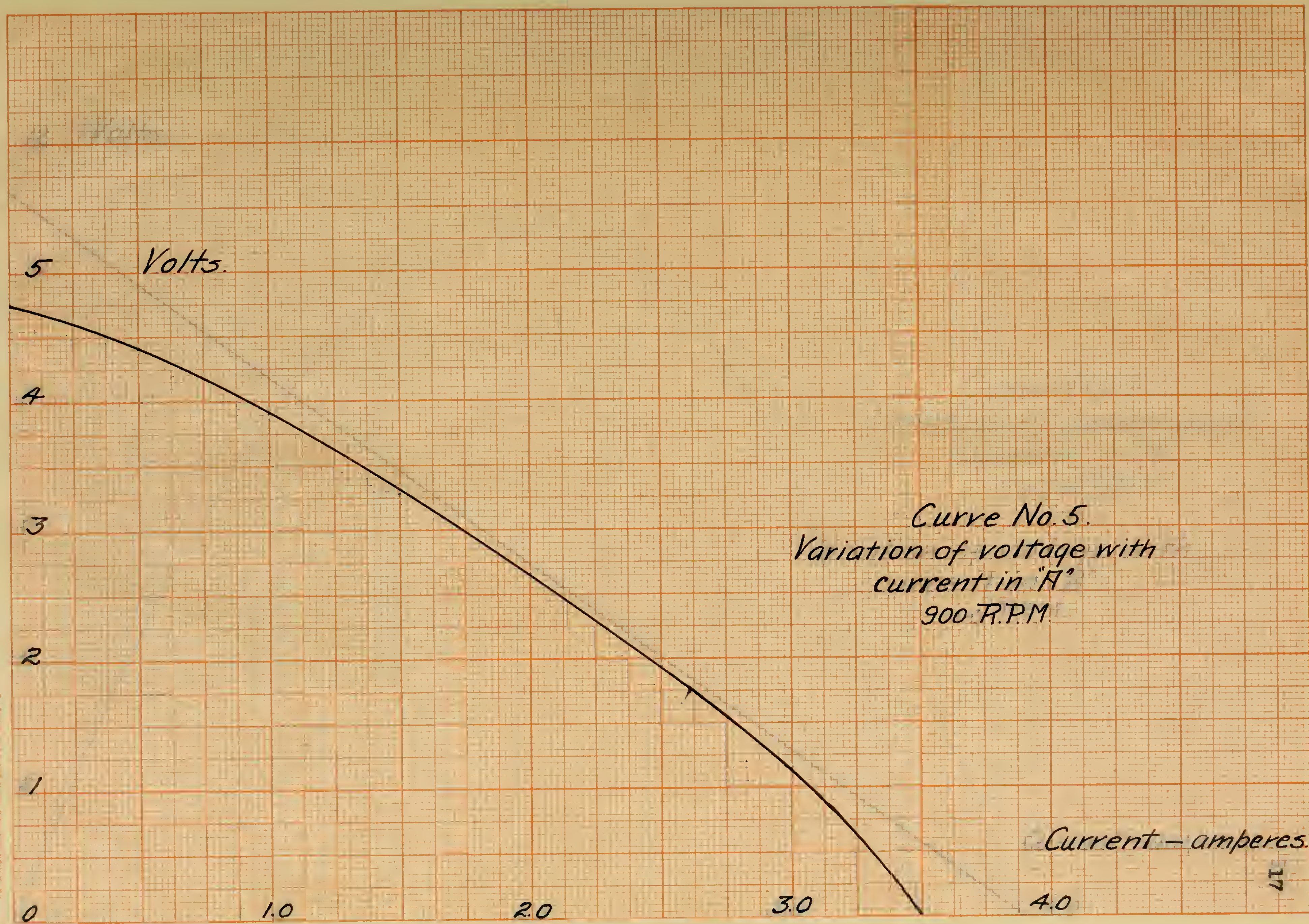
12
10
8
Open circuit volts.
6
4
2
0
200
400
600
800
1000
Curve No.2.
Variation of voltage with
speed in "B".
Rev. per minute
14

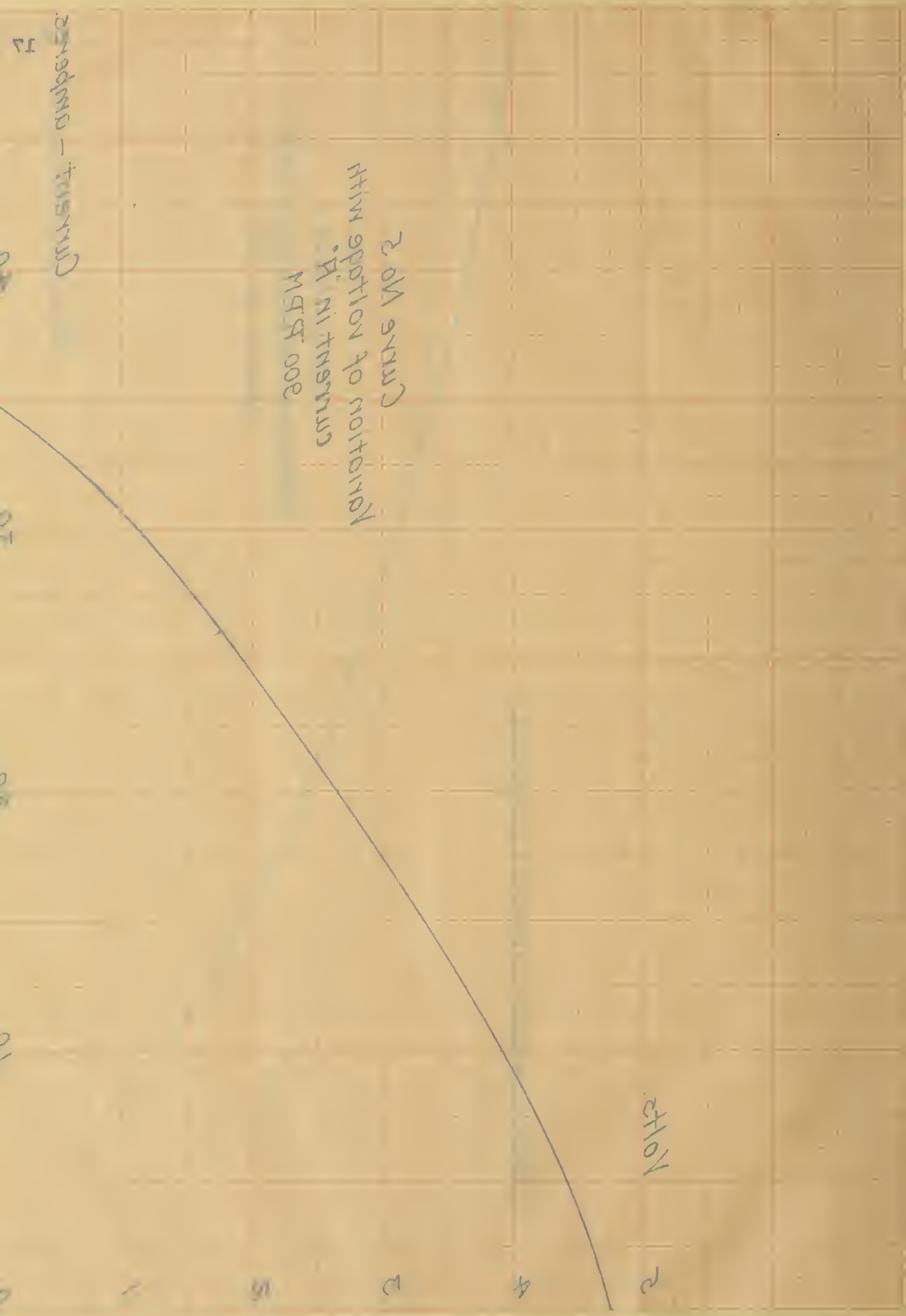

12
10
8
Open circuit volts.
6
Curve No.2.
Variation of voltage with
speed in "B".
4
2
Rev per minute
14
0

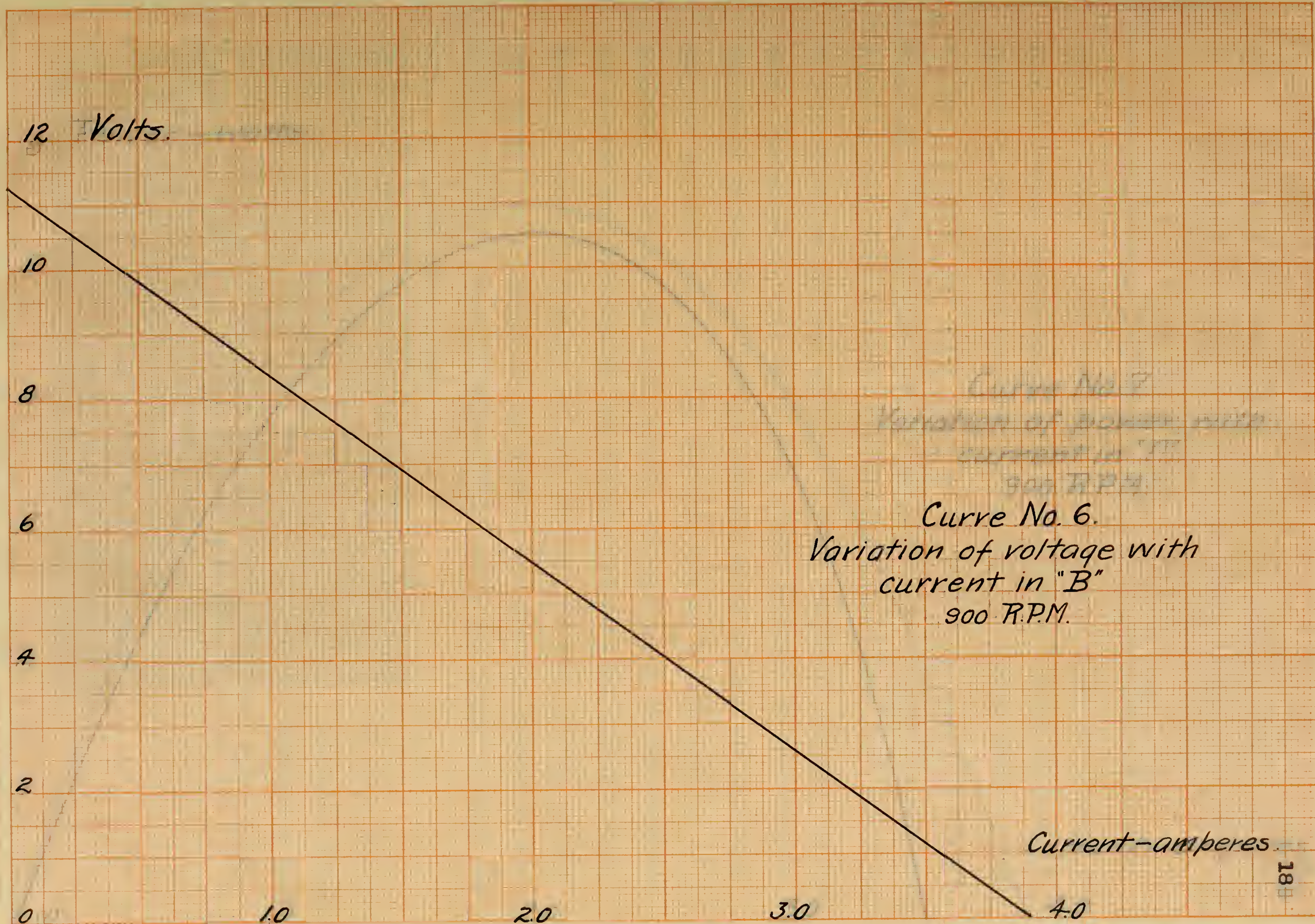

Short circuit current - amperes.
4
3
2
1
0
200
400
600
800
1000
Curve No.3.
Variation of current with
speed in "A".
Rev. per minute.


Short circuit current - amperes.
Curve No.3
Variation of current with
speed in "A"
Rev. per minute
4
3
2
1

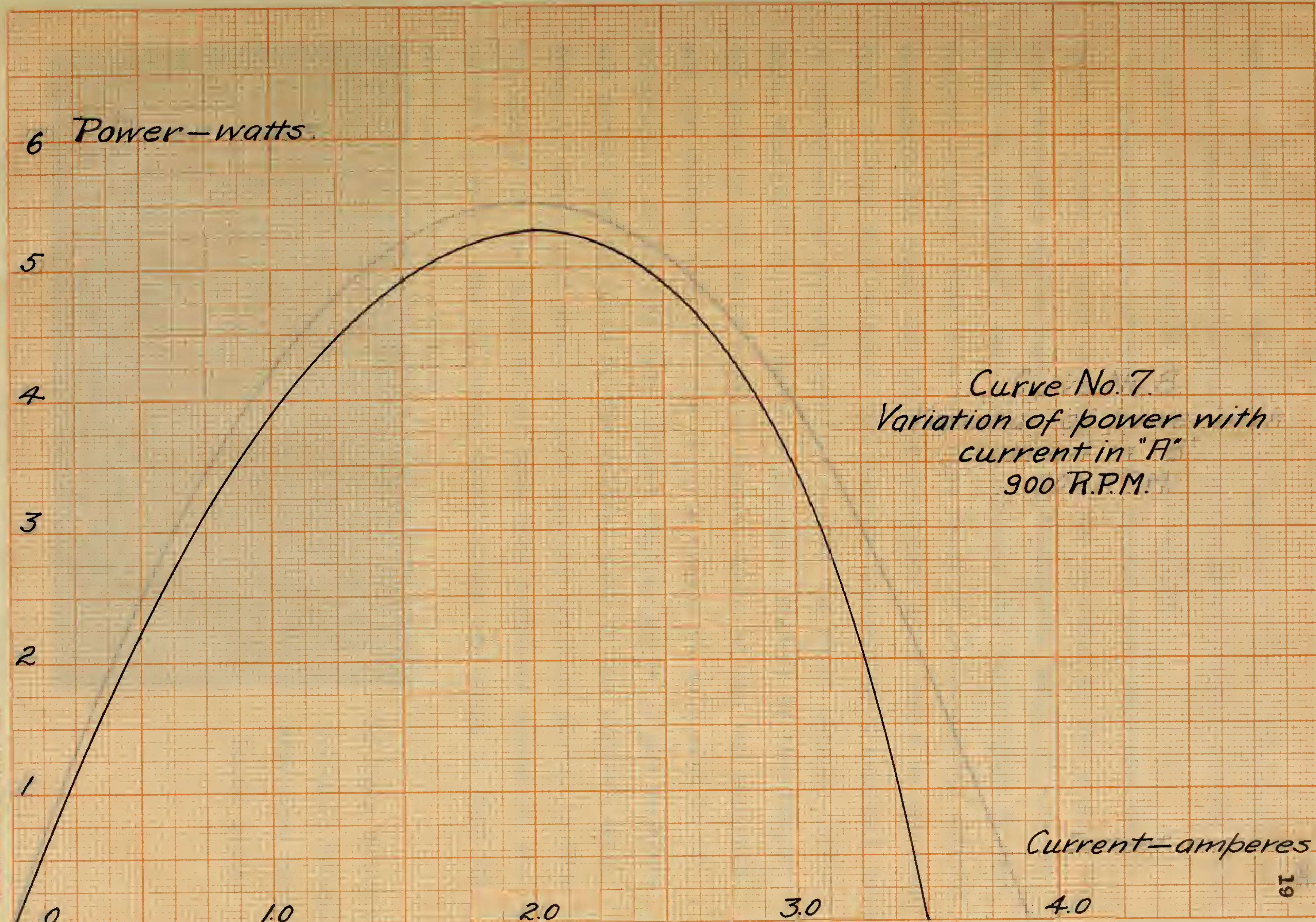

Short circuit current-amperes.
Curve No. 4.
Variation of current with speed in "B".
Rev. per minute.
0
200
400
600
800
1000
1
2
3
4
5

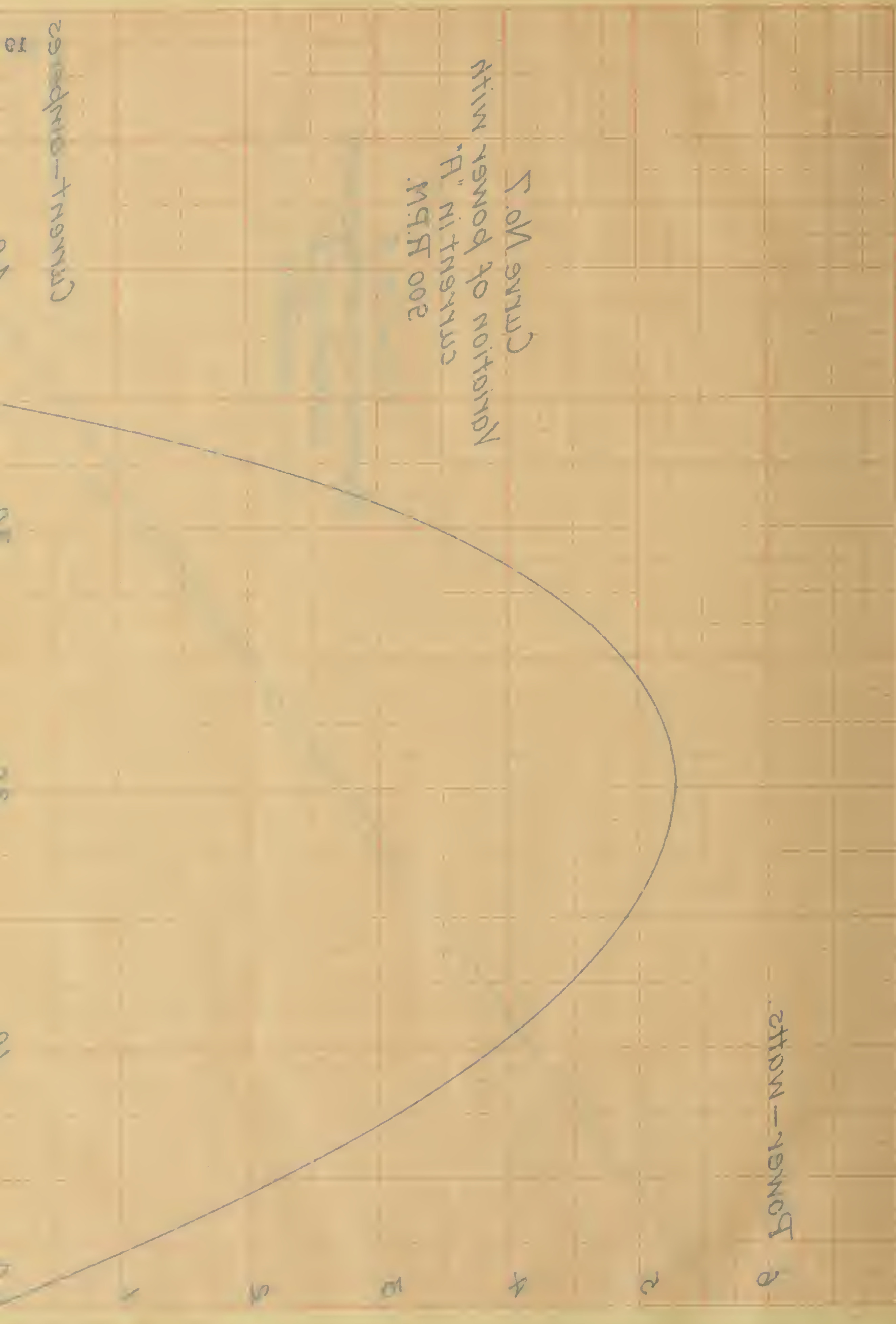

Curve No. 5.
Variation of voltage with
current in "A"
900 R.P.M.
Volts.
5
4
3
2
1
0
1.0
2.0
3.0
4.0
Current – amperes.


Curve No 5
Variation of voltage with
900 RPM
Volts
Current – amperes

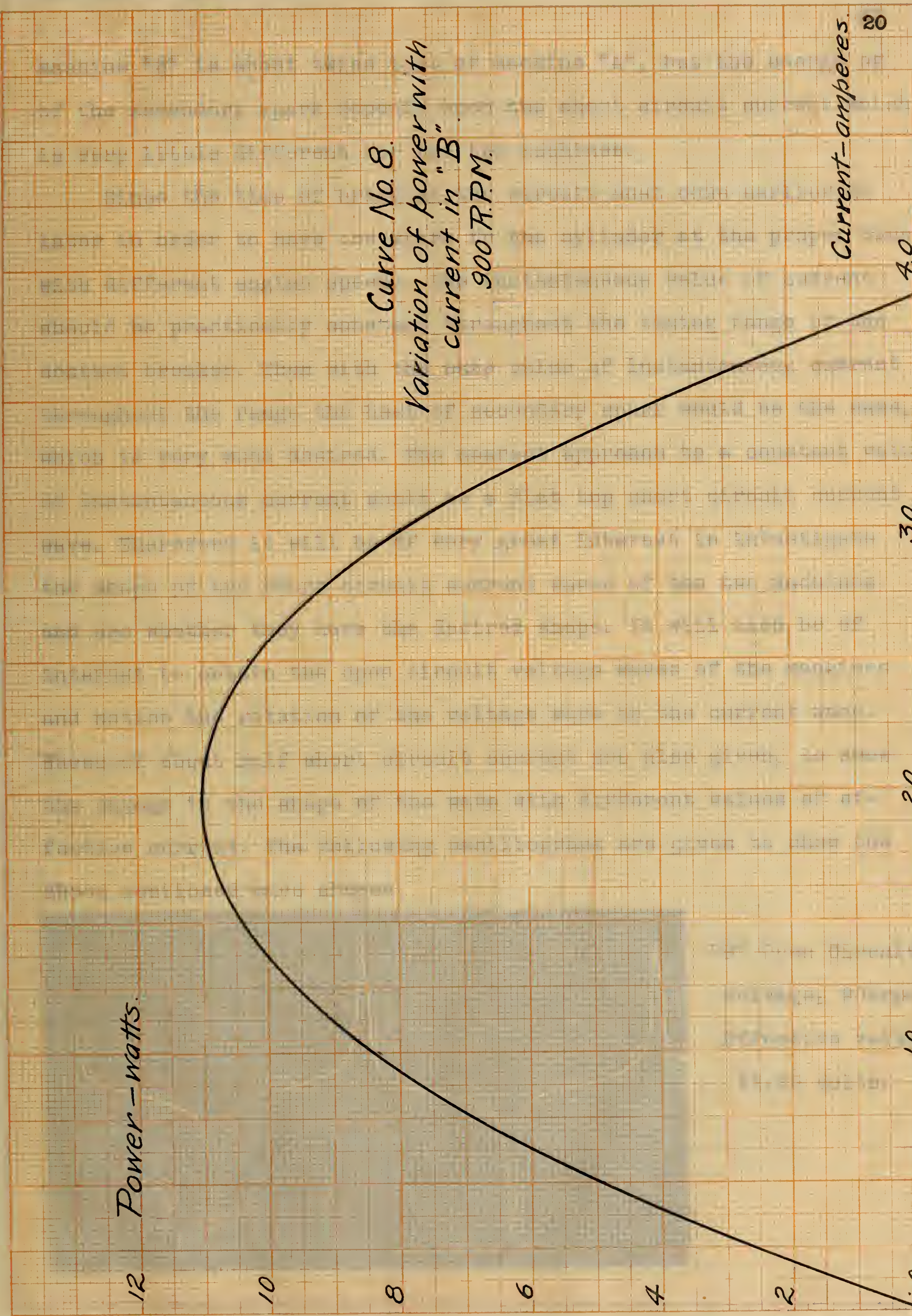


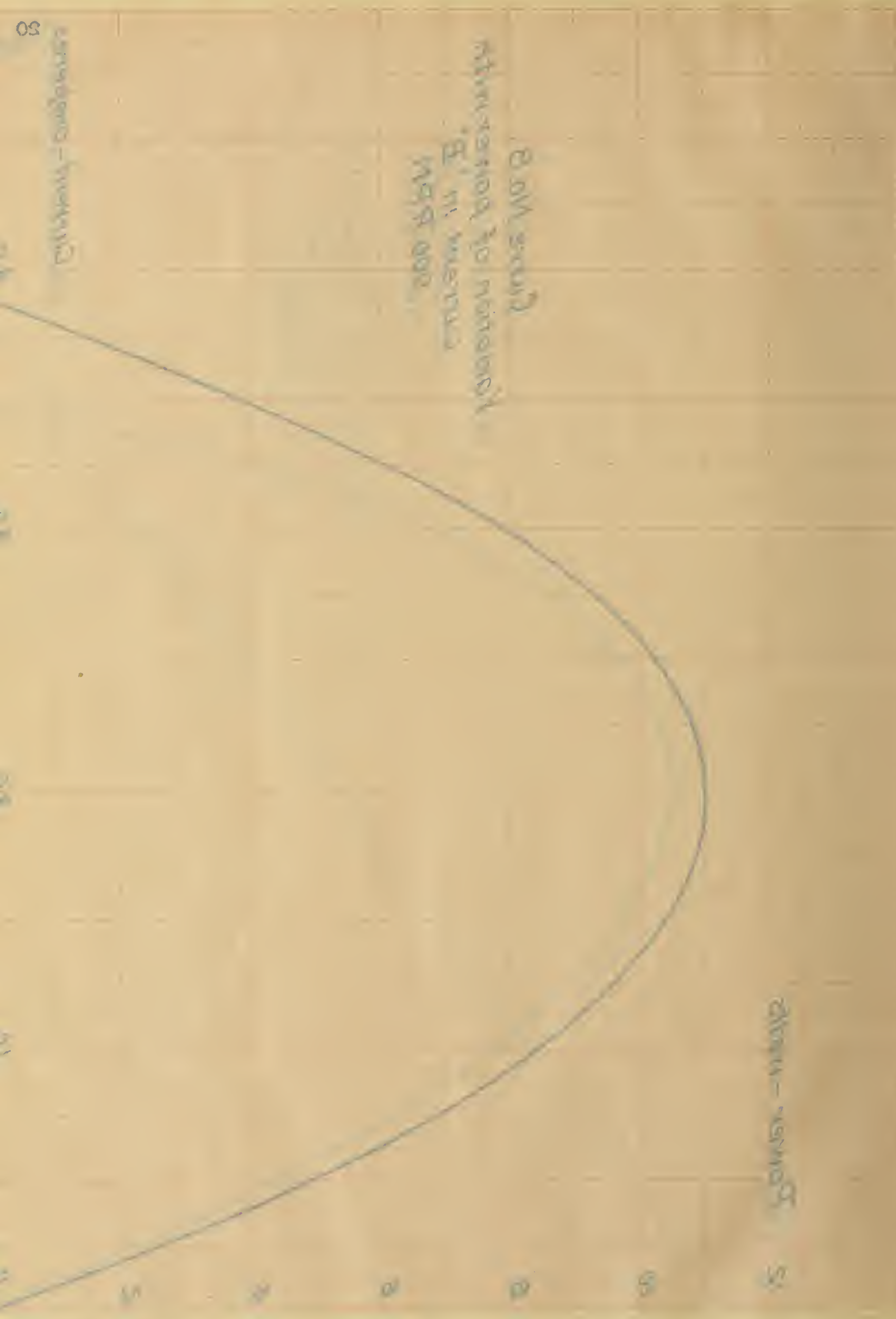
Curve No. 6.
Variation of voltage with
current in "B"
900 R.P.M.
Volts.
Current-amperes.
12
10
8
6
4
2
0
1.0
2.0
3.0
4.0


Power—watts
6
5
4
3
2
1
0
1.0
2.0
3.0
4.0
Current—amperes
Curve No. 7.
Variation of power with
current in "A"
900 R.P.M.



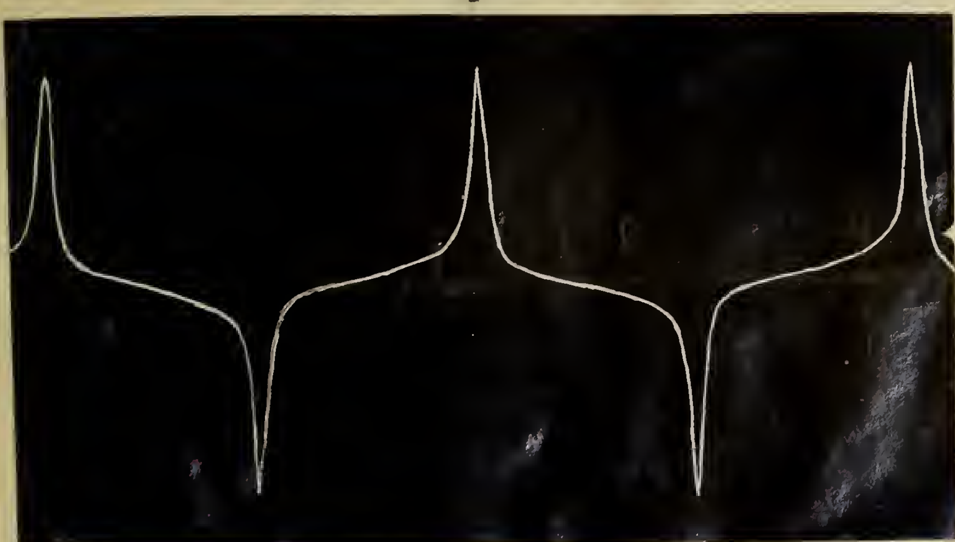
Curve No. 2
Variation of power with
current in "A".
500 R.P.M.
Power—watts
Current—amperes


Curve No. 8.
Variation of power with current in "B".
900 R.P.M.
Current—amperes.
Power—watts.
0
1.0
2.0
3.0
4.0
2
4
6
8
10
12

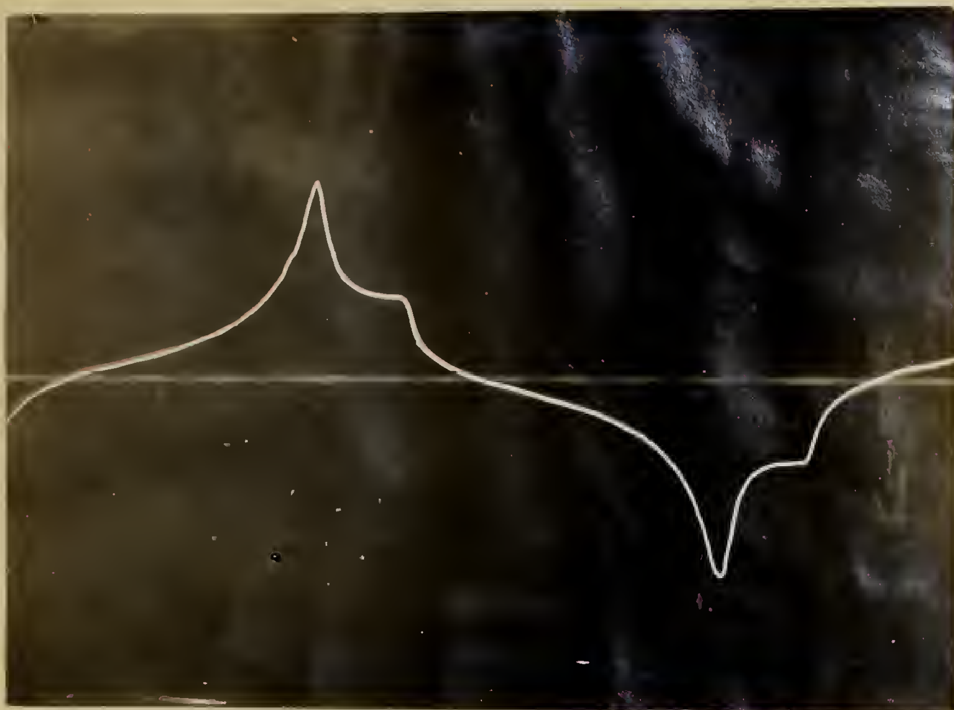


machine "B" is about twice that of machine "A", but the energy of of the secondary spark depends upon the short circuit current which is very little different for the two machines.

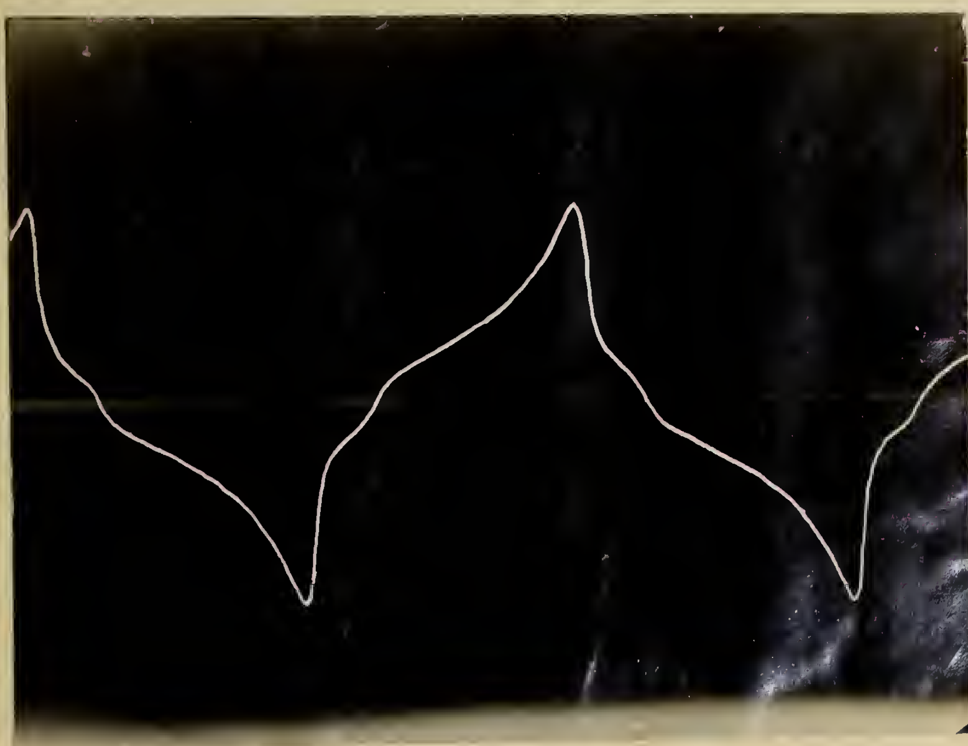
Since the time of breaking the circuit must come earlier or later in order to have the spark in the cylinder at the proper time with different engine speeds, the instantaneous value of current should be practically constant throughout the timing range of the contact breaker. Then with the same value of instantaneous current throughout the range the heat of secondary spark would be the same, which is very much desired. The nearest approach to a constant value of instantaneous current would be a flat top short circuit current wave. Therefore it will be of very great interest to investigate the shape pf the short circuit current waves of the two machines and see whether they have the desired shape. It will also be of interest to obtain the open circuit voltage waves of the machines and notice the relation of the voltage wave to the current wave. Waves of about half short circuit current are also given, to show the change in the shape of the wave with different values of effective current. The following oscillograms are given to show the above mentioned wave shapes.



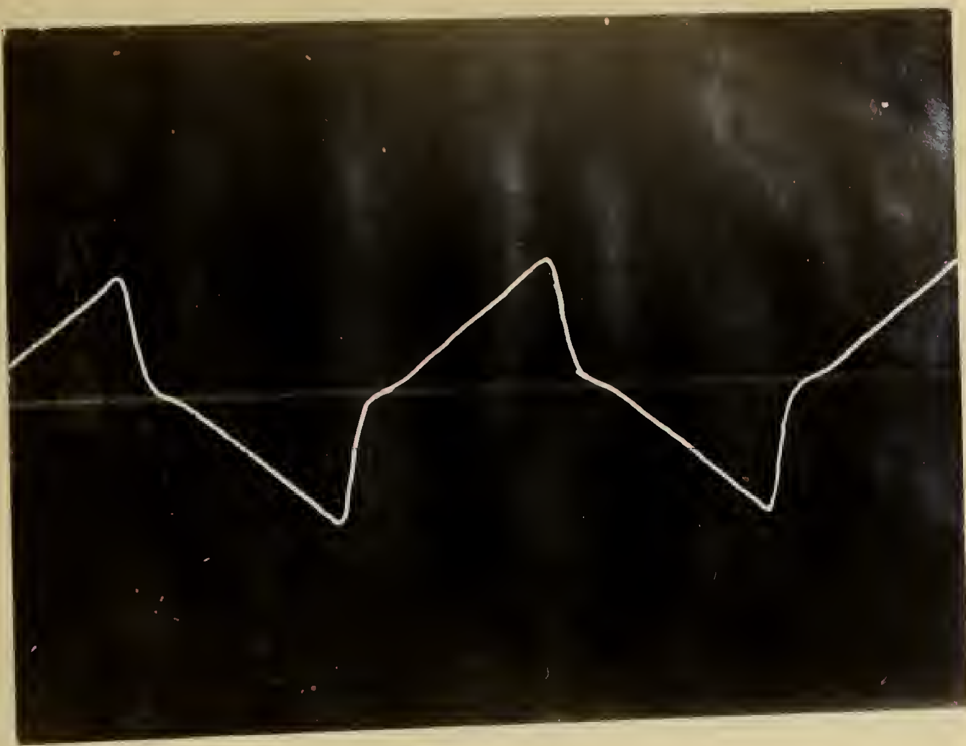
"B" Open Circuit voltage, 900rpm. Effective value 11.25 volts.



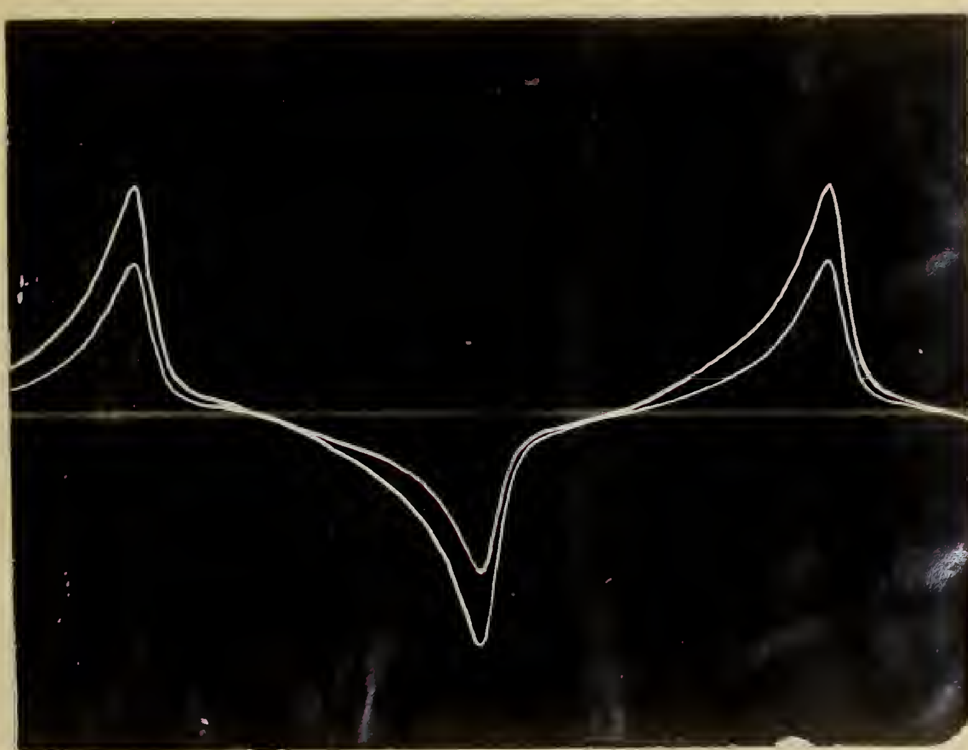
"A" Open circuit volts 900 rpm. Effective value- 4.75 volts



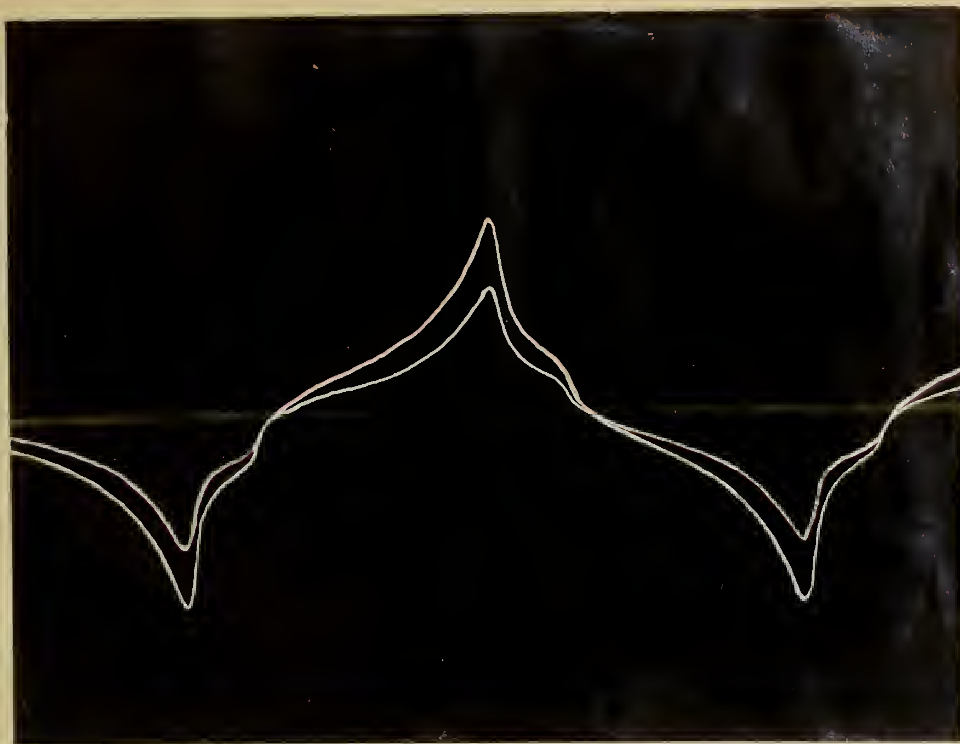
"A" Short circuit current 900 rpm. Effective value- 3.05 amp.



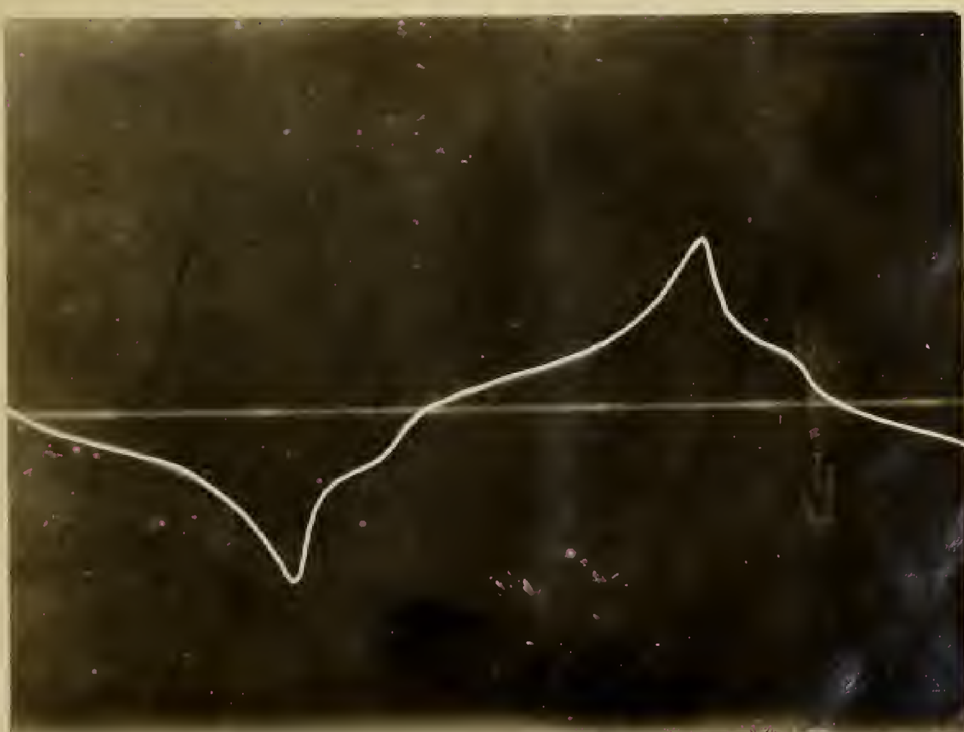
"B" Short circuit current 900 rpm. Effective value- 3.45 amp.



"B" Volts-Amperes 900 rpm. Effective values- 5.6 volts- 1.86 amp.



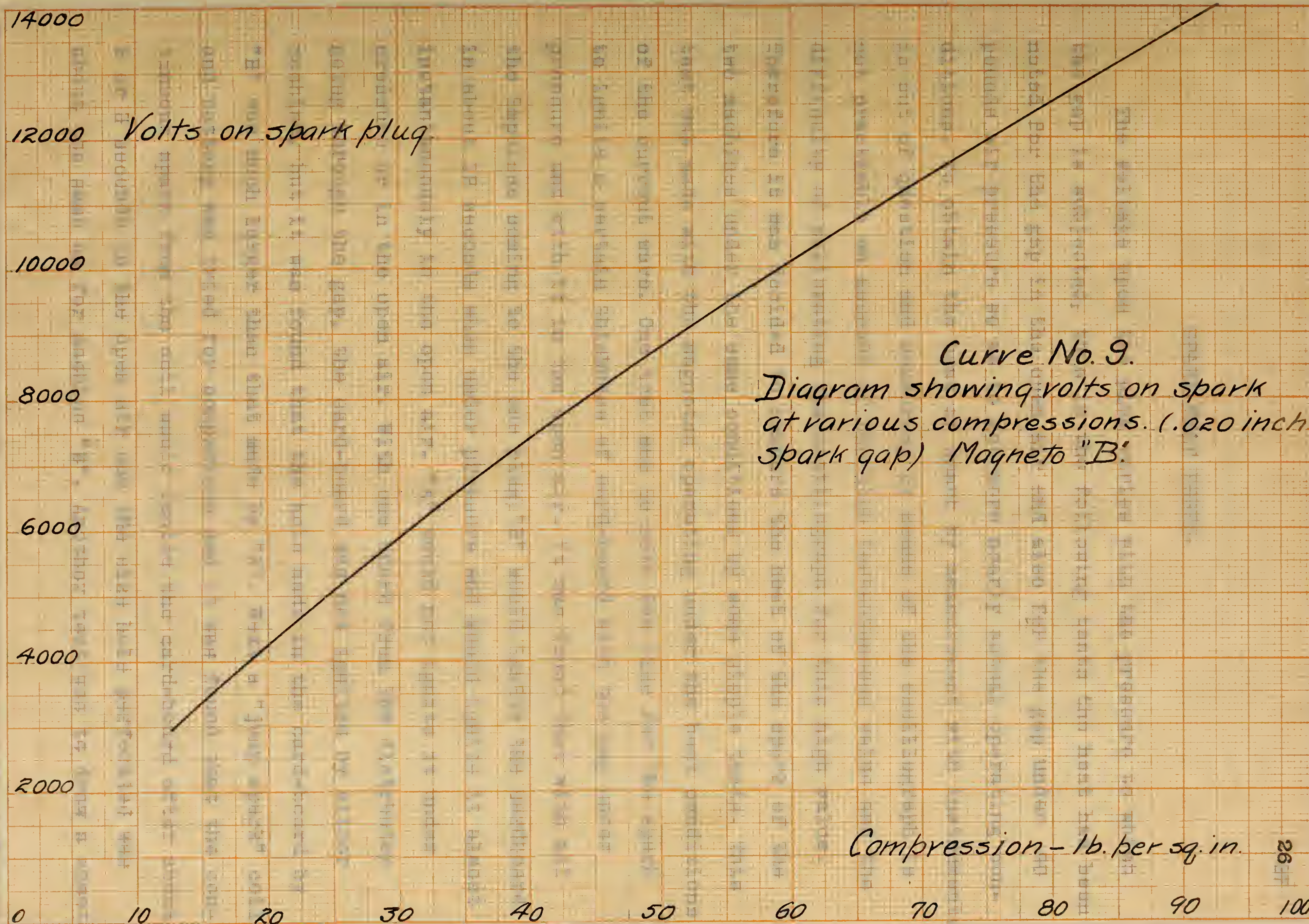
"A" Volt-amperes 900 rpm. Effective value- 3.1 volts- 1.73 amp.

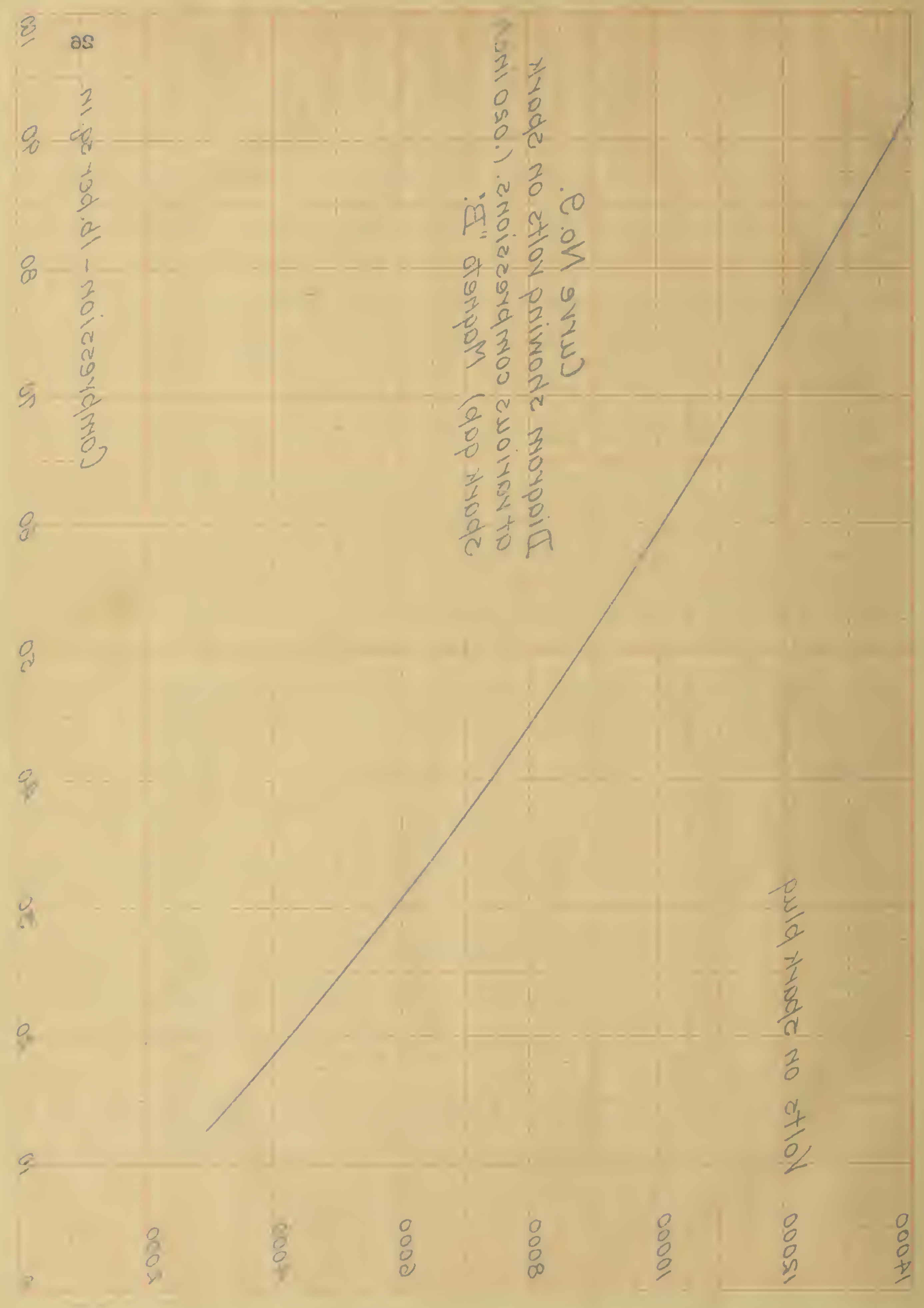


"A" Short circuit current 900 rpm. Effective value- 2.00 amp.

From the foregoing oscillograph records we find the open circuit voltage waves for both machines to be peaked, "A" having a small additional peak upon the falling portion of the curve while "B" has a very sharp single peak. The short circuit currents are within about 10% of the full short circuit current at that speed, which is sufficiently near to show the wave shape. It will be noticed from the other current waves that the larger current flattens the current wave out more, that is , raises the wave on each side of the peak. The current curve for "A" has a decided peak at short circuit showing that a flat top wave has been missed considerbly. The short circuit current wave of "B" is practically triangular, the peak being not as high as for "A". Thus this machine does not have a flat top wave either, but of the two machines, "B" has the better shape. The shape of the current wave of both machines has an advantage, which is that as the current is broken at different parts of the curve, for slow speeds it is broken near the peak and as it is advanced to the lower portion of the wave, the engine speed increases and the instantaneous value of current becomes greater. Thus we have the effect of a constant instantaneous value of current broken. However, the instantaneous value will drop considerably for "A" and also somewhat for "B" since the current does not increase sufficiently with the increase of speed. Thus from the shape of the waves we would expect better results from "B" than from "A".

To show the effect of pressure upon the voltage necessary to jump the gap of the spark plug, curve #9 is included which applies to machine "B" and is taken from a current magazine.


Curve No. 9.
Diagram showing volts on spark at various compressions. (.020 inch spark gap) Magneto "B".
Volts on spark plug
Compression - lb. per sq. in.
14000
12000
10000
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
90
100


26
Curve No. 9.
Diagram showing volts on spark plug
at various compressions (.020 inch
spark gap) Magneto "B".
Volts on spark plug
Compression - lb. per sq. in
2000
4000
6000
8000
10000
12000
14000
10
20
30
40
50
60
70
80
90
100

SPARK HEAT TESTS.

The voltage upon the plug varies with the pressure to which the gap is subjected, thus in the following tests the heat has been noted for the gap in the open air and also for the gap under 40 pounds air pressure so as to get more nearly actual operating conditions. To obtain the heat of spark by measurement with instruments is out of question and measuring by means of the oscillograph is not practiable on account of the high instantaneous value and the difficulty of calibrating the oscillograph for this high value. Therefore it was decided to compare the heat of the spark of the two machines under the same conditions by some simple tests. This test was made with the magnetos operating under the best conditions of the current wave. One test was to note the time for the spark to ignite a certain thickness of card-board with the gap under pressure and with it in the open air. It was found that with all the impulses coming to the one plug,"B" would ignite the cardboard in about 12 seconds when under pressure and would ignite it almost instantaneously in the open air. "A" would not ignite it under pressure or in the open air. With one spark from the distrbutor going through the gap, the card-board was not ignited by either machine, but it was found that the hole made in the card-board by "B" was much larger than that made by "A". Next a "jump spark" coil and battery was tried for comparison and it was found that the continuous spark from the coil would ignite the card-board after about 2 or 3 seconds in the open air and the size hole perferated was about the same as for machine "B". Another test was to draw a sheet

of paper through the gap while sparking and note the size hole perferated in the paper in each case, and it was found that the hole for "B" was much larger than for "A". A test for voltage was also made by placing a piece of oiled muslin in the gap, the muslin having previously been tested to break down at 6000 volts(effective) and noting whether or not the spark would perferate it. It was found that "B" would perferate it while "A" would not. This shows that the voltage rise for "A" is not as great as for "B".

CONCLUSIONS.

The arrangement of the windings upon "B" are such as to be very efficient, the generating winding serving also as the primary of the transformer. The secondary being wound directly upon the armature with the primary gives little chance for leakage. In addition the current wave of "B" is more nearly a flat top than for "A" so we should expect better results for this reason. The spark heat tests all indicate that the energy in the spark of "B" is much greater than for "A" and is also somewhat greater than for the battery and coil. The power developed in the armature as a generator is much greater in "B" than in "A". The fact that the voltage from "B" will perferate the oil muslin is an indication that the voltage from "B" can rise to a much higher value than for "A". Thus "B" is a much more efficient machine, is more compact, and the heat of spark delivered is very much greater.